

## FACTSHEET FOR PARTNERSHIP FIELD VALIDATION TEST

|   |  |                      |                                      |
|---|--|----------------------|--------------------------------------|
| <b>Partnership Name</b>   | Big Sky Carbon Sequestration Partnership   |                      |                                      |
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| Principal Investigator  | Lee Spangler   |                      |                                      |
| <b>Field Test Information:</b><br>Field Test Name   | Cropland Field Validation and Forestry Validation  |                      |                                      |
| Test Location   | North central Montana and Moscow Mountain, Idaho   |                      |                                      |
| Amount and Source of CO <sub>2</sub>  | Tons Source: atmosphere  |                      |                                      |
| Field Test Partners<br>(Primary Sponsors)   | Washington State University, Montana State University, Los Alamos National Lab, University of Idaho, US Forest Service |                      |                                      |
| <b>Summary of Field Test Site and Operations:</b>   |  |                      |                                      |
| <b>Cropland Field Validation</b><br>The cropland field validation test is being conducted in north central Montana which consists of 2+ million ha of cropland (the most representative cropping region in Montana), and in other select locations in the region. The predominant land use for the region is small grain agriculture (i.e, wheat, barley, peas). The region has been under cultivation since the early 1900's with soil management progressing from intensive moldboard plowing to less intensive cultivation to no-till or direct-seed management. The adoption of direct-seed management in MT is not well documented and as a part of Phase II we are utilizing satellite imagery to better document land management in the region.<br>Soil carbon sequestration in the region is being researched in 1) controlled sites to develop regional estimates of carbon storage rates as a function of management and 2) measuring, monitoring, and verifying (MMV) carbon change using proximal sensing methods at sites enrolled in a pilot carbon trading mechanism. During the cropland field validation test, existing field trials at six controlled sites (farms, with multiple fields) with a range of management practices (till vs. no till and alternate year fallow vs. continuous cropping) will be extended over the duration of the project. Several MMV techniques (lab-based and "on-the-go" visible and near infrared spectroscopy (VisNIR), laser-induced breakdown spectroscopy (LIBS), and combined VisNIR – LIBS spectroscopy) will be evaluated at eight independent enrolled sites.<br>Based upon the results of the controlled and enrolled cropland field tests, BSCSP will prepare a Cropland Terrestrial Project Planning Handbook that details cropland sequestration project design and best management practices. |  |                      |                                      |
| <b>Remote Sensing Validation Group</b><br>The project area for the MMV Field Validation Group is located within the Golden Triangle Region in North Central Montana. This region roughly includes land between Havre, Shelby, Conrad, Great Falls, and Fort Benton with the actual project area constrained to land falling within Landsat image scenes 39-26 and 39-27.<br>Field locations for data collection were determined by applying a random point generator to a Landsat Thematic Mapper (TM) Image set following an image masking process to remove non-agricultural areas. A file containing road spatial reference area was then overlaid onto the imagery and all generated points located away from a road structure were removed, resulting in 500 semi-random field reference locations. These sites were physically visited June 2007. Data collected included cropping status (vegetated or fallow), crop type, and tillage management (tillage vs. no-till). A portion of the sites  |  |                      |                                      |

visited included rangeland, as we were unable to obtain rangeland information for the image masking process. The resulting reference field data included 421 cropland sites and 101 rangeland sites. These locations included 220 fields under no-till management and 201 fields under conventional tillage management. 112 of these sites were fallowed and 309 were vegetated. Data for over 500 conservation reserve sites were provided by the Montana Farm Service Agency.

### **Forestry**

The forestry study combines lidar remote sensing with field surveys and forest stand growth modeling to characterize and predict rates of aboveground carbon sequestration in forests of the Northern Rockies. The work will focus on a case study region located on the Palouse Range of Idaho and be designed to establish a repeatable methodology by which carbon sequestration may be quantified across broader regions. During this activity, we will conduct baseline vegetation sampling (resampling of forest plots established in 2003), conduct original data analyses of a time series of airborne lidar remote sensing data, calibrate the remote sensing data to the field data using allometrics and statistical modeling, and use the results to parameterize a process-level forest growth model to extrapolate our findings to other areas. A primary deliverable of this work will be to develop a spatially explicit GIS database of aboveground forest carbon pools and rates of sequestration for the coniferous forests of the Palouse Range. Because the work will be partly based upon a unique time series of airborne lidar data, we anticipate a secondary deliverable of a peer reviewed publication outlining our work to be used as a standard methodology upon which future assessments of aboveground forest carbon can be based.

### **Research Objectives:**

The overall goal of this project is to demonstrate that terrestrial sequestration in cropland is a safe and permanent method to mitigate greenhouse gas emissions. The Partnership's objectives for this project are to quantify and determine cropland management practices that optimize carbon sequestration (controlled site field validation) and develop MMV protocols to evaluate carbon sequestration for enrolled farms (enrolled farm field validation). Remote sensing, using Landsat imagery, will be evaluated as a cost effective verification tool for monitoring enrolled acreages and to provide the areal extent of potential C sequestration for the region.

### **Remote Sensing Validation**

The objective of this component is to determine if remote sensing can be used to accurately identify agricultural practices specified in carbon contract agreements as specified by the National Carbon Offset Coalition. This will include using remote sensing techniques to identify no-till, crop intensity, and conservation reserve lands. Crop intensity is defined as the proportion of years a field includes crop cover as opposed to summer fallow; conservation reserve indicates the use of perennial crop cover as opposed to annual cover. We have hypothesized that these management practices can be classified with > 85% accuracy through the object-oriented (O-O) classification of Landsat satellite imagery. The resulting land use data will also be used to calculate cropland carbon sequestration attributed by current cropland management trends, thereby estimating regional carbon intake contributed by no-till, conservation reserve, and crop intensity. The potential for increased sequestration given universal adoption of these management practices was also assessed.

### **Forestry**

To date, almost all forest based lidar remote sensing studies have been based upon single-date data acquisitions, and are therefore limited in that forest carbon can only be quantified at one specific point in time to determine a static carbon pool. We will build upon an initial lidar dataset acquired on the Palouse Range of northern Idaho in 2003 by flying a new lidar dataset in early summer 2009 at the same location. By developing this lidar time series, we will be able to assess not only the static carbon pools in 2003 and 2009, but we will additionally be able to: quantify rates of aboveground carbon sequestration from measured tree growth across a range of forest types and site conditions; quantify the impact on carbon storage of forest disturbance (particularly harvest) during this 6-year interval; and utilize the 2003 and 2009 field and lidar data to initialize FVS and its carbon accounting tool to develop spatially explicit

projections of forest growth and carbon sequestration for this region.

#### **Summary of Modeling and MMV Activities:**

##### **Cropland Field Validation**

Standard carbon measurement, employing dry combustion and modified pressure calcimeter analysis for total carbon and inorganic carbon, respectively, is a well documented and accepted method. This method relies on efficient sampling designs to measure SOC temporally and spatially.

Visible and near-infrared diffuse reflectance spectroscopy (VisNIR) spectral signatures of materials are defined by their reflectance, or absorbance, as a function of wavelength. These signatures are due to electronic transitions of atoms and vibrational stretching and bending of structural groups of atoms that form molecules and crystals. SOC and SIC are both molecular components of soil and VisNIR has been shown to semi-quantitatively estimate SOC and SIC in soils. “On-the-go” VisNIR has the advantage of quickly collecting large amounts of spatial VisNIR data to map soil variability within fields.

Laser-induced breakdown spectroscopy (LIBS) is fundamentally an elemental analysis technique. LIBS involves directing a focused Nd:YAG onto the surface of the target material. The focused laser ablates a small amount of surface material producing a supersonically expanding plasma of electronically excited ions, atoms, and small molecules. These excited species emit light as they relax back to lower electronic states at wavelengths indicative of the identity of the elements present in the sample. Some of this emission is directed into a dispersive spectrometer and the resulting spectrum is detected with a charge-coupled device (CCD) detector. Combining VisNIR and LIBS sensors should theoretically provide quantitative determination of SOC and SIC.

##### **Remote Sensing Validation**

The Remote Sensing Validation Group has completed their research pertaining to Phase II. Extensive literature review validated that the RandomForest model remains the best option for image classification in the context of this study due to its robustness in handling unbalance data sets, a tendency to not overfit, and an ability to provide a within-model estimate of classification accuracy.

##### **Forestry**

The team has begun analysis of multitemporal lidar data collected in 2003 and 2007 in order to make a preliminary assessment of whether our study methodology is likely to provide direct measurement of aboveground C sequestration into forests over a 4-year timespan. Results indicate that aboveground C sequestration is quantifiable over this timespan using both ground sampling data as well as lidar data. For example, forest metrics quantified in the field between 2003 and 2008 indicate that (1) forest growth was quantifiable and (2) could be used to derive the annual increase in forest aboveground biomass during the period. These data are corroborated by lidar-measured forest height, which also shows that height increase can be measured using lidar remote sensing data. These results are guiding further analysis of lidar data collected within the larger Moscow Mountain study area in 2009.

#### **Field Accomplishments in the past year:**

**Lab-based VisNIR spectroscopy** provided somewhat more accurate predictions than *in situ* on-the-go VisNIR sensing. In terms of SOC predictive accuracy, our results are largely consistent with those previously published by Christy (2008), but on-the-go VisNIR was not able to capture the subtle SOC variability in Montana soils. Estimating SOC in fields with low SOC variability did not produce usable results for either on-the-go or lab-acquired spectra. Spectra from prepared samples did, however, yield semi-quantitative regional and hybrid calibrations for soil clay. Regional clay models derived from on-the-go VisNIR spectra did not provide useful predictions; however, hybrid on-the-go soil clay models, using up to seven local samples in the calibration approached semi-quantitative predictive levels (RPD = 1.4, RPL = 3.4). This suggests on-the-go VisNIR spectroscopy has potential for mapping soil clay, assuming that local samples are available for recalibration at every field. Results comparing spectral ranges of the two

instruments suggest increasing the spectral range of the on-the-go sensor similar to that of a lab-based spectrometer will not improve predictions for this application. Our findings indicate that on-the-go VisNIR might not be effective in mapping fields with relatively low target property variability. Given the better performance with processed soil samples in the laboratory, researchers and equipment designers might consider developing instruments to process soils on-the-go, in the field.

#### LIBS MMV:

To the best of our knowledge, this study represents the first rigorous validation of LIBS calibrations for field-scale characterization of soil carbon using a significant number (78) of intact soil cores without pre-treatment. Using LIBS with a spectral range of 200-300 nm and employing partial least squares 2 regression (PLS2R) modeling, we achieved semi-quantitative validation accuracies for total carbon (TC) ( $r^2 = 0.63$ , RPD = 1.6, SEP = 6.0 g kg<sup>-1</sup>, SEL = 0.9 g kg<sup>-1</sup>) and inorganic carbon (IC) ( $r^2 = 0.66$ , RPD=1.7, SEP = 5.3 g kg<sup>-1</sup>, SEL = 1.03 g kg<sup>-1</sup>). Soil organic carbon (SOC) predictions appeared unacceptable ( $r^2 = 0.22$ , RPD=1.1, SEP = 3.2 g kg<sup>-1</sup>); however the low validation  $r^2$  and RPD values could be due to low SOC variability ( $\sigma = 3.47$  g kg<sup>-1</sup>) with standard error of laboratory measurement (SEL) estimated at 1.37 g kg<sup>-1</sup>. A more rigorous evaluation of LIBS accuracy to measure SOC *in situ* will require interrogating soil cores with greater SOC variability.

Until recently, univariate calibrations were the norm for LIBS analysis. A key finding of this study was that predictions were improved using a larger number of peaks in a PLS2R model. Regression coefficients from PLS2R models suggested that calibrations utilized stoichiometric relationships between C and elements related to C in the soil matrix. The primary C emission (247.8 nm) was an important predictor for TC, IC, and SOC. Additionally, Ca (210.2, 211.3, and 220.9 nm), Mg (279.55-280.4 nm, 285.26 nm), and Si (251.6 nm, 288.1 nm) were important predictors for estimating the three measures of soil carbon. The relatively narrow spectral range (200 – 300 nm) of the LIBS spectrum recorded in this study; however, omitted primary emissions from elements related to soil carbon, including primary Ca, O, H, and N. Based on the results of this study, increasing the spectral range to the full LIBS spectrum (200 – 800 nm) could increase predictive accuracies for *in situ* measurement of both inorganic and organic C.

Following are preliminary results from a second LIBS experiment (2008; 200-800 nm) using standard PLS1 regression.

| Model      | N   | RPD | SEP-adj.<br>g/kg | RPL  | SB<br>% | NU<br>% | LC<br>% | $r^2$ |
|------------|-----|-----|------------------|------|---------|---------|---------|-------|
| VisNIR TC  | 316 | 1.4 | 5.9              | 21.3 | 1       | 20      | 79      | 0.55  |
| VisNIR IC  | 316 | 1.8 | 4.6              | 10.5 | 1       | 28      | 71      | 0.69  |
| VisNIR SOC | 316 | 1.2 | 3.5              | 6.5  | 2       | 43      | 55      | 0.33  |
| LIBS TC    | 316 | 1.6 | 5.3              | 19.0 | 0       | 34      | 66      | 0.62  |
| LIBS IC    | 316 | 2.0 | 4.1              | 9.4  | 2       | 20      | 78      | 0.75  |
| LIBS SOC   | 316 | 1.0 | 4.3              | 8.0  | 0       | 76      | 24      | 0.03  |

$\sigma_{\text{SEL}}$  = standard error of laboratory measurement (TC=0.28 gkg<sup>-1</sup>, IC=0.44 gkg<sup>-1</sup>, SOC=0.55 gkg<sup>-1</sup>)

SEP = standard error of prediction;

SEP-adj = adjusted standard error of prediction =  $\sqrt{(\sigma_{\text{SEP}}^2 - \sigma_{\text{SEL}}^2)}$

RPL = Ratio of prediction error to laboratory error ( $\sigma_{\text{SEP-adj}} / \sigma_{\text{SEL}}$ )

RPD = ratio of C std. deviation to SEP-adj ( $\sigma_C / \sigma_{\text{SEP-adj}}$ ); SB = squared bias (% of MSD)

NU = non-unity with 1:1 line (% of MSD); LC = lack of correlation (% of MSD)

We will likely re-calibrate TC, IC, and SOC models for the second LIBS and VisNIR experiment using PLS2 regression. A reviewer for our current LIBS manuscript (first LIBS experiment) suggested we use PLS2 regression because total carbon and inorganic carbon data were highly correlated. PLS2 regression tries to take advantage of correlated response variables during the model building procedure. We had previously experimented with PLS2 regression in VisNIR research and did not find significant improvements over PLS1. However, PLS2 regression models improved LIBS IC and SOC prediction

accuracy by nearly 10%.

LIBS spectra from the second experiment were calibrated to 23 major and trace elements in soils. Calibration results are encouraging, particularly for elements relevant to soil characterization. These results are exploratory and preliminary. This information could be used to enhance IC and SOC calibrations using the strength of PLS2 regression.

Partial least squares leave-one-out crossvalidation results for 23 major and trace soil elements using LIBS spectra (200-800 nm).

| Element        | Ti   | Mg   | Na   | Al   | V    | Mn   | La   | Ca   | Fe   | Zr   | Si   | Nd   | K    | Rb   | Cu   | Zn   | Pb   | Ba   | Sr   | U    | Cr   | Ni   | P    |
|----------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| RPD            | 2.6  | 2.0  | 2.0  | 1.9  | 1.9  | 1.8  | 1.8  | 1.8  | 1.8  | 1.7  | 1.7  | 1.7  | 1.6  | 1.6  | 1.4  | 1.4  | 1.1  | 1.1  | 1.1  | 1.1  | 1.0  | 1.0  | 0.9  |
| r <sup>2</sup> | 0.85 | 0.77 | 0.75 | 0.75 | 0.72 | 0.71 | 0.70 | 0.69 | 0.69 | 0.67 | 0.67 | 0.66 | 0.64 | 0.62 | 0.53 | 0.50 | 0.28 | 0.26 | 0.21 | 0.17 | 0.07 | 0.05 | 0.00 |

Highlighted elements are of primary interest for soil characterization.

## Remote Sensing

Classification (2007) results included producer's accuracies of 91% for NT and 31% for tillage when applying Random Forest to image-objects generated from a May Landsat image. Low classification accuracies were attributed to the misclassification of conservation-based tillage practices as NT. Crop and CR lands resulted in producer's accuracies of 100% and 90%, respectively. Crop and fallow producer's accuracies were 95% and 82% in the 2007 classification; misclassification within the fallow class was attributed to pixel-mixing problems in areas of narrow (>100 m) strip management. A between-date normalized difference vegetation index approach was successfully used to detect areas "changed" in vegetation status between the 2007 and prior image dates (2004-2006) for four sub-regions within the overall project area; classified "changed" objects were then merged with "unchanged" objects to produce final classification maps for crop intensity status for 2004-2007. A crop intensity of 1.0 indicates continuous cropping (no summer fallow), a 0.75 crop intensity indicates 3 of 4 years cropped as opposed to fallow, and 0.5 indicates that 2 of 4 years were cropped. Crop intensity status is important as CCX guidelines indicate that carbon credit will not be given for years under fallow.

Resulting statistics showed that 22% of lands classified as CR had occurred outside of the Conservation Reserve Program (CRP). These lands might have been included within CRP at one point, but were no longer under CRP contract as of 2007 (according to data provided by the Montana Farm Service Agency). Roadside survey results indicated that 56% of the evaluated region was under NT in 2007, with 44% practicing some form of tillage. Crop intensity estimates for 2004-2007 indicated that only 5% was under continuous cropping. These observations show the regional potential for an increased incorporation of NT and continuous cropping.

The application of carbon sequestration estimates to the 2007 land use data roughly predict that 59,497 t soil carbon yr<sup>-1</sup> (Watts, 2008) might be sequestered through the universal adoption of NT and a 1.0 rotation (continuous cropping). The conversion of this cropland to NT management under a 1.0 crop intensity, and the maintenance of land currently under CR management within this relatively small percentage (11%) of Montana cropland has the ability to sequester 2% of the projected annual CO<sub>2</sub> equivalents emitted by the District of Columbia, USA (DC-AQD, 2005). Financial incentives through carbon credit programs might motivate land managers to make these management changes, and to maintain CR lands.

## Forestry

In September, 2009, our field data collection crew completed the measurement of 2,310 trees located on 86 plots. Of these 86 plots, approximately two-thirds were undisturbed between 2003-2009, while one-third were disturbed (i.e. thinned or clearcut), allowing us to investigate the impact of both growth and land management on C storage and fluxes across the 50,000 acre landscape. In addition to these field data collection activities, we made significant progress in acquiring remote sensing data necessary for the project. In particular, the airborne lidar remote sensing data flown on 6/30/09 were pre-processed and delivered to the University of Idaho by September 15, and RapidEye™ AG provided high resolution passive satellite imagery of the study area to complement the airborne lidar data on 7/8/09.

We also completed the following significant accomplishments: field data collection, lidar data preprocessing and delivery, preliminary analysis of previous lidar data (collected in 2003 and 2007) and field data (collected 2003 and 2008).

### Moscow Mountain Study Area

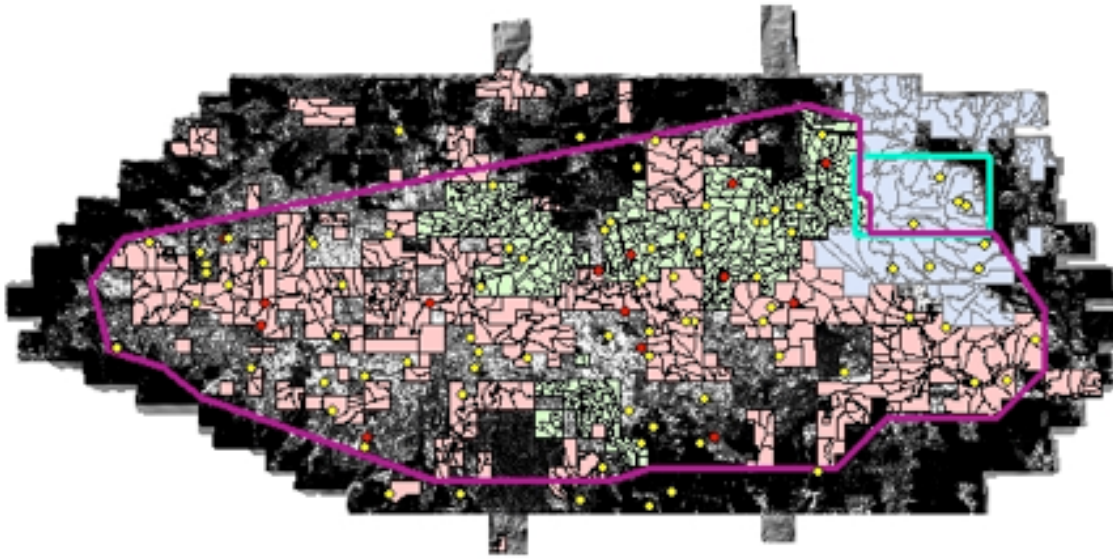


Figure 1. Moscow Mountain forestry study area. Red and yellow dots represent locations of the field plots sampled during the summer of 2009 for the purposes of this study. The dark mapped area denotes the lidar acquisition of 2003, the green outline denotes the lidar acquisition area for 2007, and the magenta outline denotes the lidar acquisition for summer 2009. Salmon, green, and gray areas denote the various forest stands for use in the monitoring and validation effort. The East-West (horizontal) dimension of the acquisition area is approximately 30 kilometers.

#### Summarize Target Sink Storage Opportunities and Benefits to the Region:

- Results from standard and proximal sensing SOC measurements are applicable to within the defined study area.
- All methods are applicable to terrestrial sequestration projects globally.

#### Cost:

**Total Field Project Cost:**  
**\$1,635,089**

DOE Share: \$1,388,226 84.9%  
Non-DoE Share: \$246,863 15.1%

#### Field Project Key Dates:

Baseline Completed: 6/30/08  
Drilling Operations Begin: NA  
Injection Operations Begin: NA  
MMV Events: NA

#### Field Test Schedule and Milestones (Gantt Chart):

| Task 7.0 -  | Q1-06 | Q2 | Q3 | Q4 | Q1-07 | Q2 | Q3  | Q4 | Q1-08 | Q2 | Q3  | Q4   | Q1-09 | Q2 | Q3 | Q4 | Q1-10 | Q2      |
|---|-------|----|----|----|-------|----|-----|----|-------|----|-----|------|-------|----|----|----|-------|---------|
| Task 7.1 - Planning   |       |    |    |    |       |    |     |    |       |    |     |      |       |    |    |    |       |         |
| Task 7.2 - Controlled Test Soil Carbon Sampling and Calibration |       |    |    |    |       |    |     |    |       |    |     |      |       |    |    |    |       |         |
|   |       |    |    |    |       |    | Tm4 |    |       |    | Tm8 |      |       |    |    |    | Tm13  |         |
| Task 7.3 - MMV on Enrolled Sites/Farms                          |       |    |    |    |       |    |     |    |       |    |     |      |       |    |    |    |       |         |
|   |       |    |    |    |       |    |     |    | Tm6   |    |     | Tm11 |       |    |    |    |       | Tm15,16 |
| Task 7.4 - Cropland terrestrial Project Planning Handbook       |       |    |    |    |       |    |     |    |       |    |     |      |       |    |    |    |       |         |
|   |       |    |    |    |       |    |     |    |       |    |     |      |       |    |    |    |       |         |

#### Additional Information